September 12, 2002

Combustion Technology Development Needs and Opportunities

Combustion Technology University Alliance Workshop, Salt Fork Lodge, Cambridge, OH

John L. Marion

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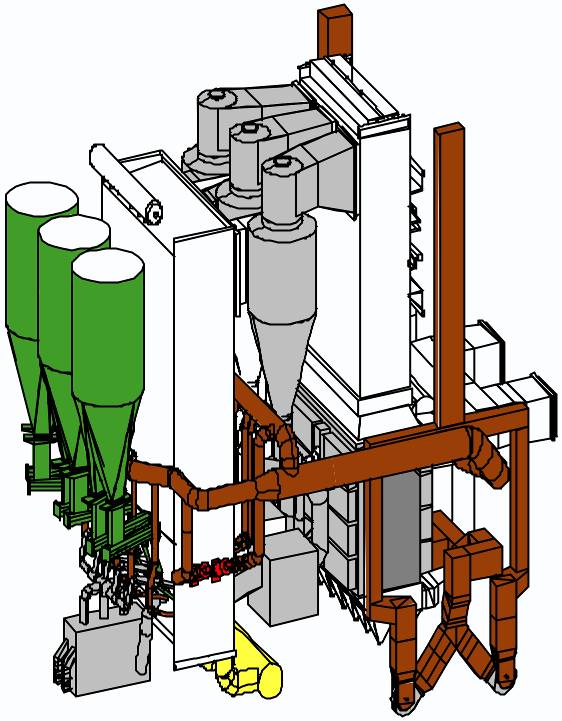
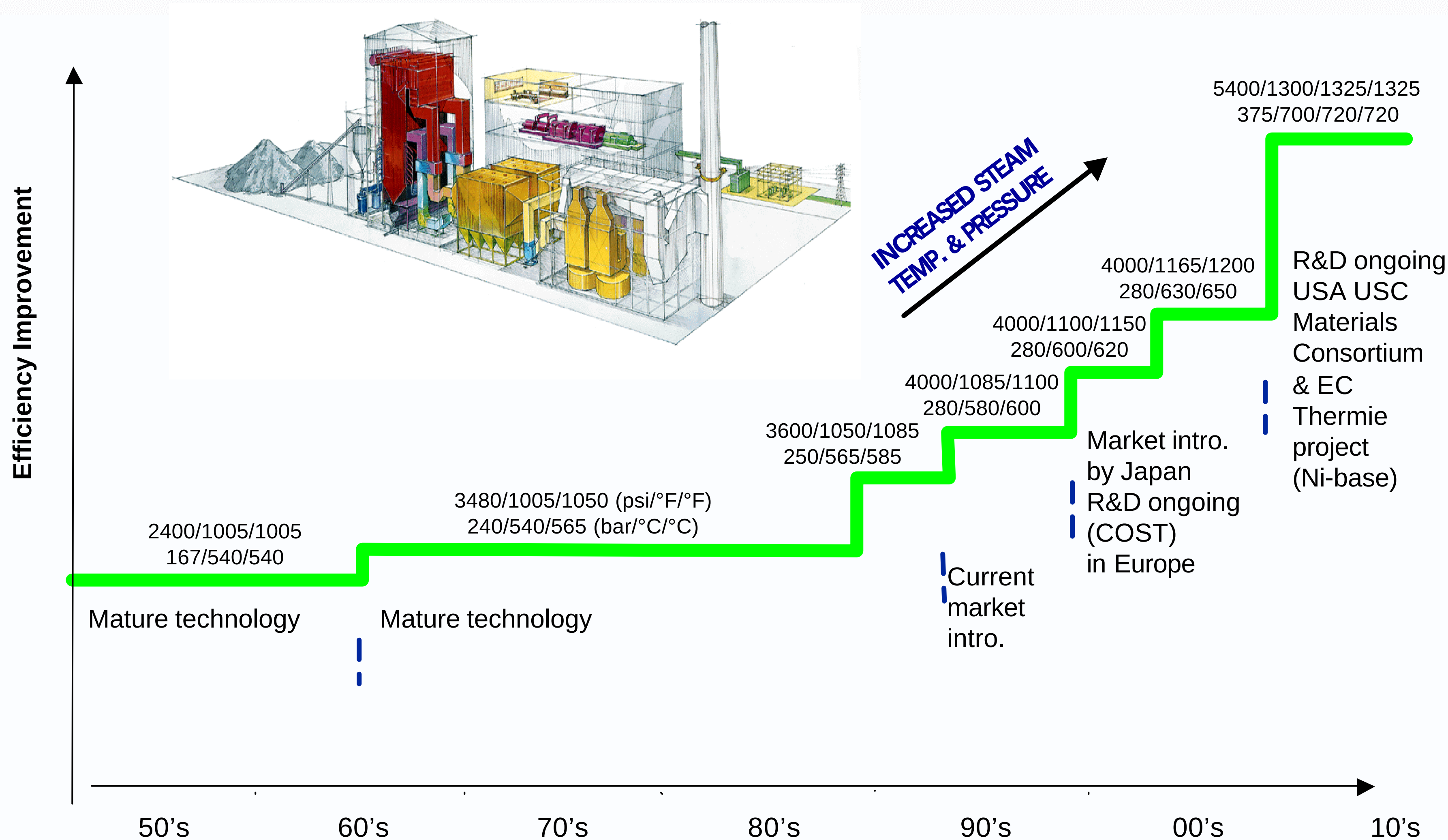
Roadmap for Combustion-based Power

- **Ultra-supercritical steam conditions**
  - increase efficiency
- **Circulating Fluid Bed (CFB) and "advanced CFBs"**
  - low costs, low emissions, fuel flexibility
- **CO2 Capture**
- **Emissions controls**
  - for new and existing, and integrated and post



ALSTOM's view includes four (4) legs to advance coal combustion-based power technology

Ultra-supercritical technology Trend ALSTOM



Cost Effective Materials are Key

Partnership: Ultrasupercritical Materials

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- DOE, the State of Ohio Office of Coal Development and industry have teamed to develop next generation technology which will provide efficiency and environmental gains

BABCOCK BORSIG POWER

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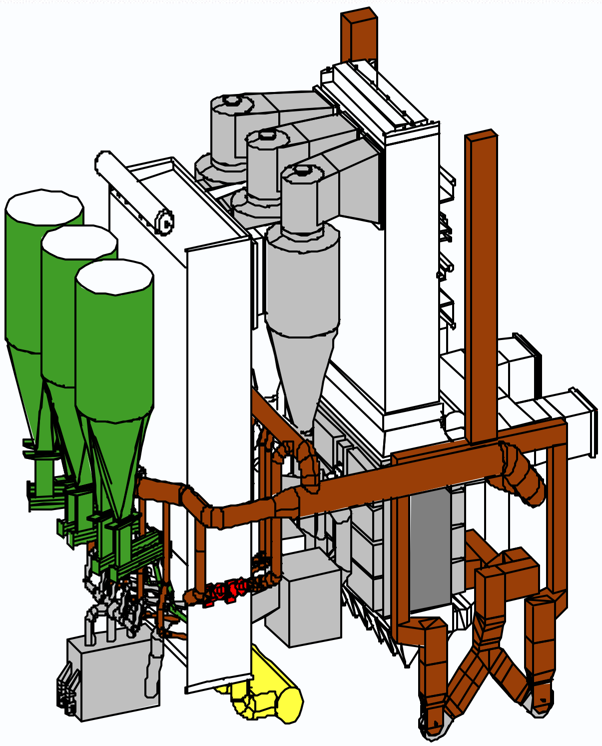
- A uniquely qualified industry team - Energy Industry of Ohio, ***all*** the major US boiler manufacturers, a renowned national lab, Ohio organizations, and EPRI

- An aggressive goal - 1400^{o}F steam temperature
  - Looks beyond Japanese and European practice and materials to where US alloys may be best

Circulating Fluidized Bed Power Plants Today

- Utilize lower cost solid fuels which are difficult to burn
- Fuel flexibility enables low cost spot market purchases
- Inherent Low NOx
  - Low combustion temperatures and staged combustion; also amenable to in-furnace (cyclone) ammonia injection for SNCR
  - NOx emissions from 0.06 to 0.25 lbs/MM BTU
- Inherent Low SOx as a result of limestone injection
  - Typical removals of 90 - 97%+; up to 98.5% with secondary equipment



Economic Utilization of Low Cost Fuels

Future
Circulating Fluidized Bed (CFB)

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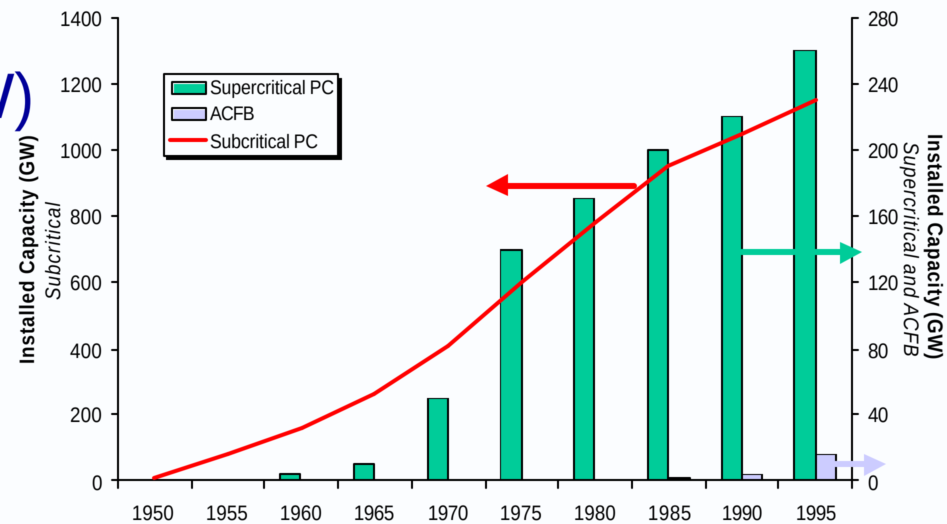
- Reduce Costs (new designs)
- Ultra Clean (integrated APC)
- Grow in Size (up to 600 MW)
- Improve Efficiency by Supercritical and USC conditions
- Enable Re-Powering
- Enable CO2 capture

Summary of Global Installed Coal Capacity
for Sub-critical PC, Super-critical PC, and CFB boilers



JLM03/Combustion-DOE-Sept11'02.ppt

CFB's are early in the adoption and innovation curve

"Advanced CFB" or "Circulating Moving Bed [CMB]"

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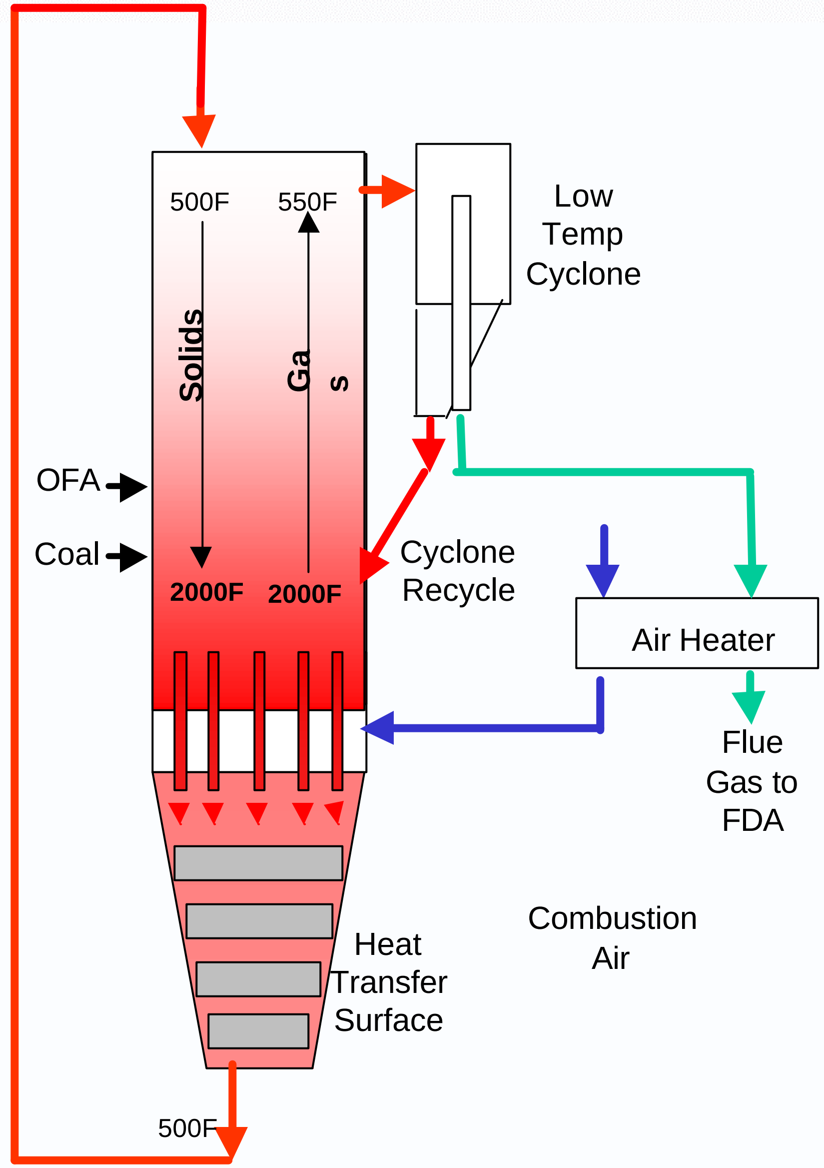
- Separate heat transfer from combustion
- More effective surface allows supercritical steam conditions at lower cost
- Lower cost than ordinary CFB for conventional duty
- Lower auxiliary power
- Potential Pathway to in situ CO2 capture



CO2 Capture in Combustion Systems

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- **“Tail-end” CO_2 capture**
  - adsorption/stripping process (MEA,MEA/MDEA, and physical absorbents)

- **Oxygen combustion**
  - internal (membrane) or external (ASU) O_2
- **Other options**
  - oxidation/reduction cycles
  - carbonate capture
  - chemical looping

Innovative technology options just now emerging

For both combustion-based and gasification-based power

O_2 Fired CFB for CO2 Capture

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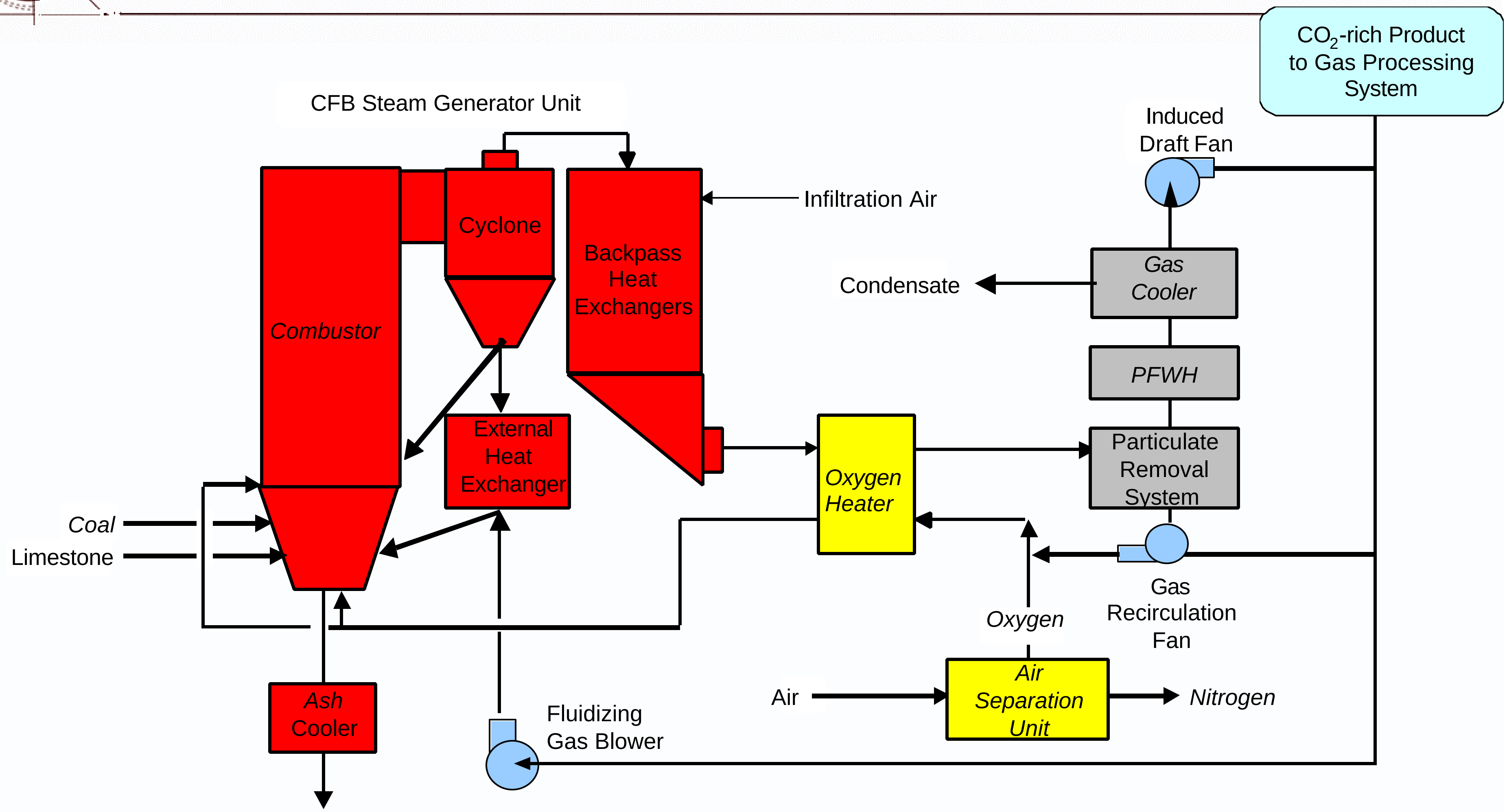


Oxy-fuel combustion in a CFB requires less flue gas recycle in order to maintain combustion temperature

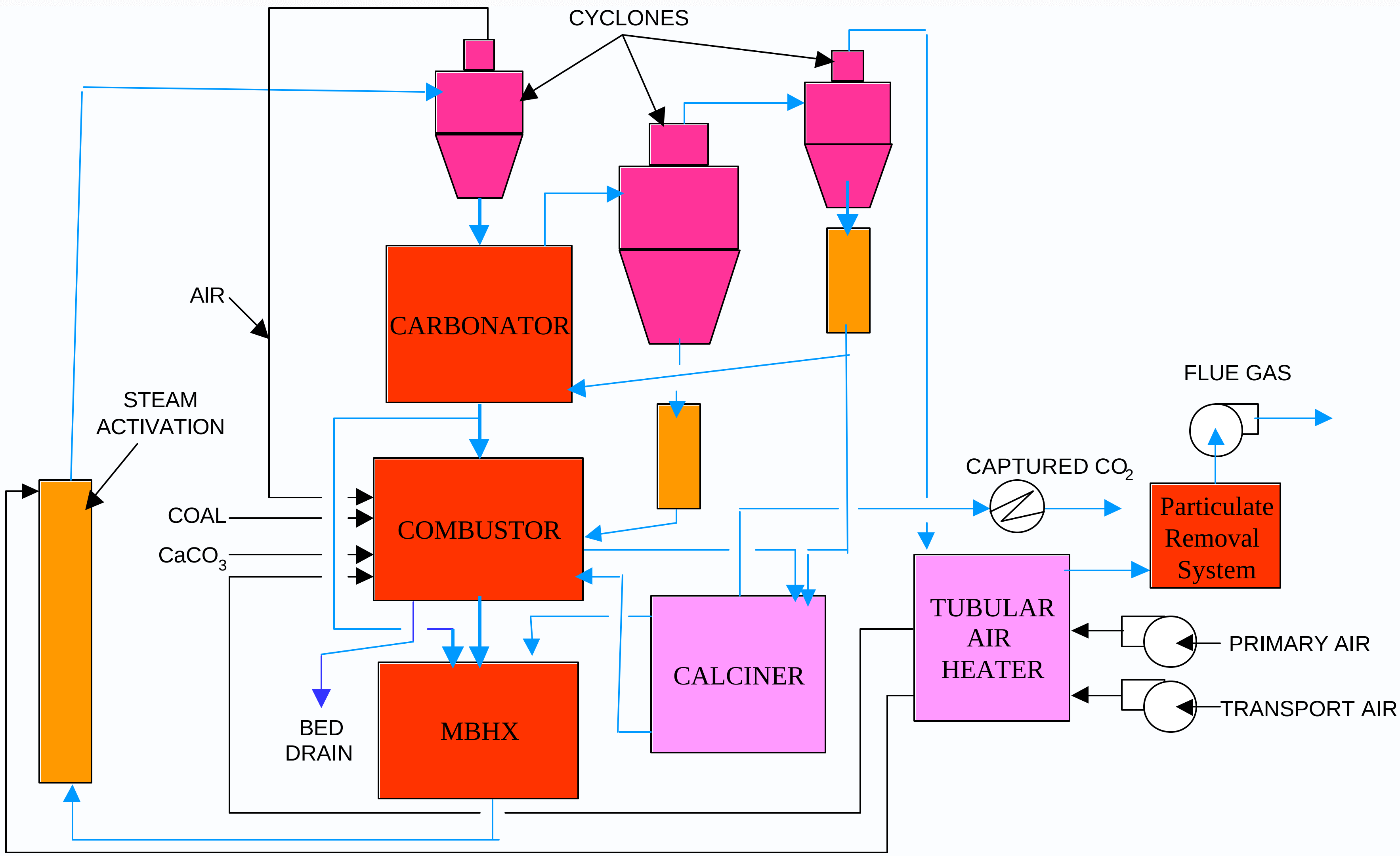
Carbonate Cycle for CO_2 Capture ALSTOM

Below 750^{o}C….
$CaO + CO_2 \rightarrow CaCO_3 + Q$

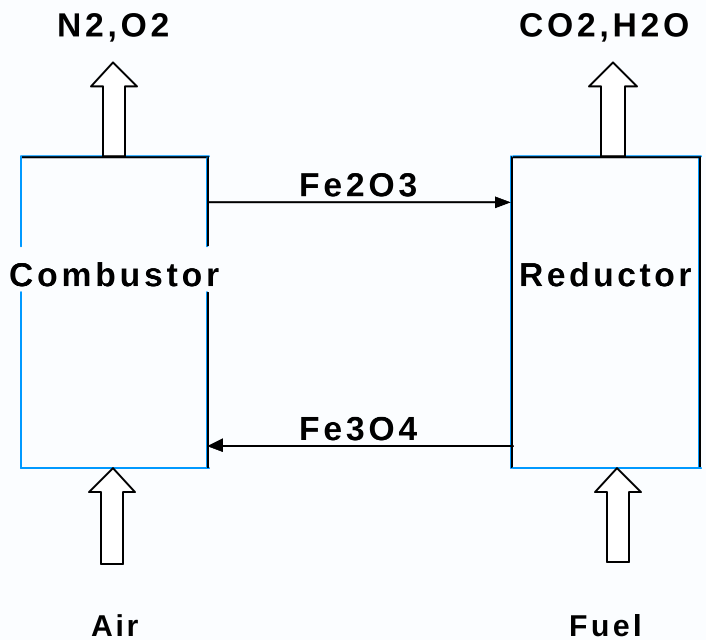
Above 1050^{o}C….
$CaCO_3 + Q \rightarrow CaO + CO_2$

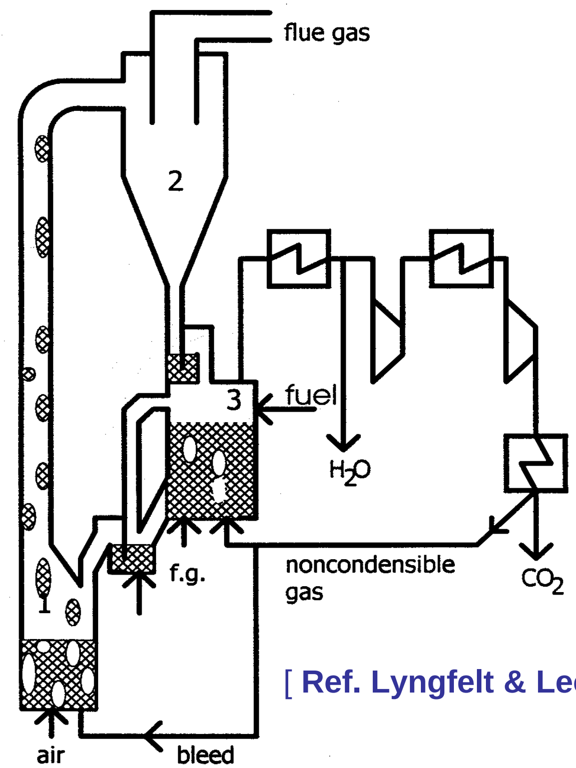
Potential combustion process with FBC's

High Temperature Carbonate Process for CO2 Capture



CO2 Capture through Chemical Looping





[Ref. Lyngfelt & Leckner]

- Atmospheric Pressure
- Oxygen carriers (Cu, Cd,Ni, Mn, Fe, Co)
- Potential combustion process with interconnected FBC's

Environmental Controls

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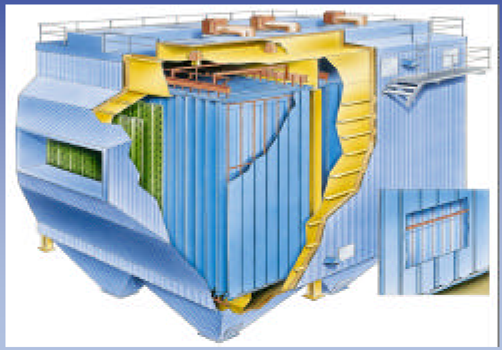
Wet & Dry Flue Gas Desulphurisation

Mercury Control

Wet and Dry Electrostatic Precipitator



De NOx

Technical Opportunity to Integrate with Combustion Process

Roadmap for the Future

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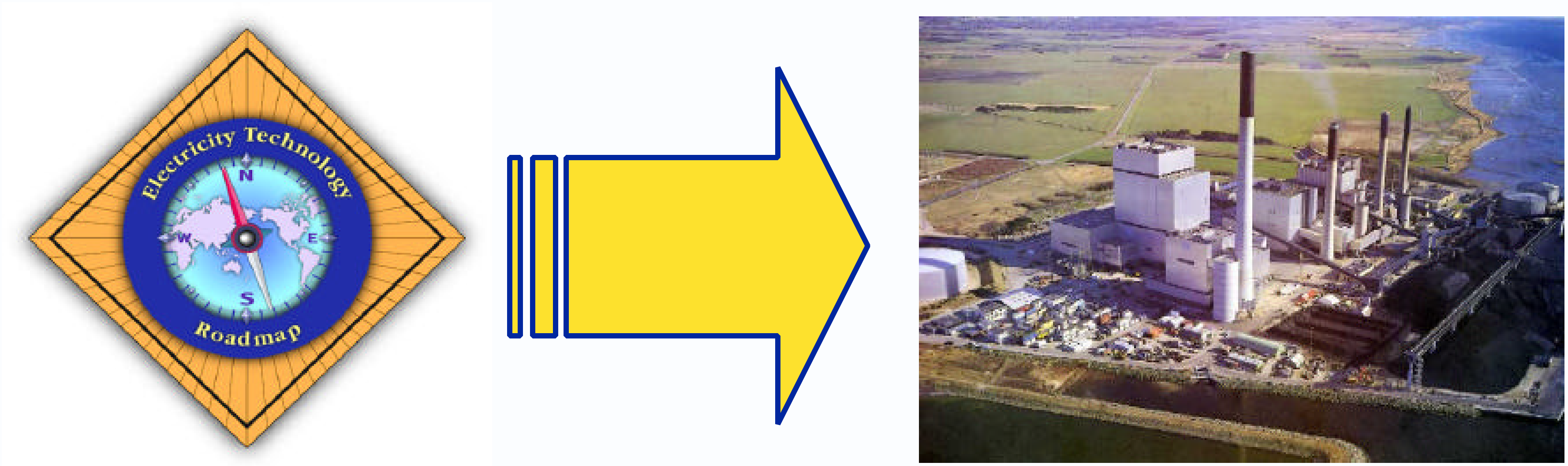
CURC - Coal Utilization Research Council

An ad hoc group of coal suppliers, users, transportation, and equipment supplier organizations with the common interest to define and realize a vision for the future of coal power through industry/government collaboration



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Advanced Combustion-based Steam Power Plant Roadmap

CURC December, 2001

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Attributes	Today	2006	2008	2010	2020
Captial Cost(w/CO2 Removal)	1100(n/a)	1000(n/a)	900(<1400)	800(<1200)	800(<1000)
Efficiency(w/CO2 Removal)	40(n/a)	44(n/a)	45(>34)	46(>39)	50(>45)
Availability	95	95	95	95	95
SO2 Removal %	95+	98.5	98.5	99	99+
NOx (lbs/Mbtu)	0.1	0.1	0.05	0.05	0.01
Hg Removal %	30-90+	80-90+	90-95	90-95	95+
CO2 Removal %	n/a	n/a	n/a	90+	99
Waste Utilization	30	50	75	75	90+
Particulate Emis. (lb/Mbtu)	0.03	0.01	0.01	<.01	<.01
Steam Temperature	1100	1150	1200	1250	1400
Steam Pressure	3600	4000	4000	5000	5600
Development		Alloys for <1400; steam turbine; innov. Boiler & plant designs; APC integration (Sox/Hg/Part)	Valves for <1400; steam turbine; innov. Boiler & plant designs; APC integration (Sox/Hg/Part)	Valves for <1400; steam turbine; innov. Boiler & plant designs; APC integration (Sox/Hg/Part)	shift R&D to CO2 capture
Demonstration	1) 1100+ °F PC; 2) 300 MW CFB: 3) APC Int. CFB	1) 1150°F PC (700 MW); 2) Supercritical CFB	1) 1200°F PC (700 MW); 2) Adv. CFB (50 MW)	1) 1250°F PC (700 MW); 2) 600 MW CFB; 3) Adv. CFB (250 MW)	1) 1400°F PC (700 MW)
R&D cost	0	$83	$50	$42	$10
Demonstration Cost	0	$445	$270	$580	$220
Subtotal Cost	$0	$528	$320	$622	$230
Total Cost					**$1,700**

Details of Advanced Combustion-based Steam Power Plant Research and Development
CURC December, 2001

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DEVELOPMENT

2006	Cost[1]	2008	Cost[1]	2010	Cost[1]	2020	Cost[1]	Totals[1]
Development and testing of alloys up to 1400 F	$35	development and testing of valves for up to 1400	$2	Development and testing of valves for up to 1401	$2			$39
Design studies of innovative plant designs	$3	Design studies of innovative plant designs	$3					$6
Steam Turbine development	$5	Steam Turbine development	$5	Steam Turbine development	$5			$15
CFB cost reduction development	$10	CFB cost reduction development	$10					$20
Advanced combustion systems development to enable high temp. cycles and future CO2 capture	$20	Advanced combustion systems development to enable high temp. cycles and future CO2 capture	$20	Advanced combustion system development to enable high temp. cycles and future CO2 capture	$25			$65
Integrated APC in CFB development	$10	Integrated APC in CFB development	$10	Integrated APC in CFB development	$10	Integrated APC in CFB development	$10	$40
CO2 capture for combustion systems included in Carbon management roadmap [2]	*$50*	*CO2 capture for combustion systems included in Carbon management roadmap [2]*	*$50*	*CO2 capture for combustion systems included in Carbon management roadmap [2]*	*$200*	*CO2 capture for combustion systems included in Carbon management roadmap [2]*	*$50*	*$350*
Subtotal Development	$83		$50		$42		$10	$185

DEMONSTRATION

1150 F PC plant demo. (700 MW)	$215	1200 F PC plant demo. (700 MW)	$220	1250 F PC plant demo. (700 MW)	$220	1400 F PC plant demo. (700 MW)	$220	$875
Supercritical CFB demonstration	$200			600 MW CFB	$180			$380
Integrated SO2/Hg/Part. APC in CFB	$30	Small demo. (50 MW) "adv. CFB repowering demo.	$50	Large Demo. (250 MW) "adv. CFB demo.	$180			$260
		CO2 capture for combustion systems included in Carbon Management Roadmap [2]	*$200*	*CO2 capture for combustion systems included in Carbon Management Roadmap [2]*	*$200*	*CO2 capture for combustion systems included in Carbon Management Roadmap [2]*	*$100*	*$500*
Subtotal Demonstation	$445		$270		$580		$220	$1,515
Grand Total	**$528**		**$320**		**$622**		**$230**	**$1,700**

[1] Cost in millions U.S. Dollars

[2] Costs included in Carbon Mangement Roadmap

Advanced Combustion Research Needs

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Flow

- ? bed fluid dynamics
- ? clusters/solids distribution
- ? attrition (coal/lime/ahs)
  - depreciation
  - fragmentation
- ? fluidizing nozzles
- ? 2 fluid modeling
  - dense phase
  - sub-routines/sub models
- ? cyclone technology
  - separation technology
- ? non-cyclone approaches
  - separation technology
- ? input on size fuel/lime on combustion performance sulfur capture
- ? flow measurement/control
  - neural network/fuzzy logic
- ? agglomeration
- ? flow sensors
  - density meters
  - spacial and temporal distributions
- ? erosion/corrosion
  - modeling
  - refractory
- ? bed mixing
- ? scale-up issues
  - mixing
  - flow
  - pilot to utility scale

erosion/co.

? $\frac{dp}{dt}$ ~ agglomerat ion meter

Materials

- ? coatings
- ? refractory
- ? materials

Heat Transfer

heat transfer as a function of (geometry, surface parameters)

solid to solid heat transfer
wall heat transfer
extended surface

moving bed heat transfer
hybrid beds
FBHE –fluid bed heat exchangers (external on recycle loop)

Cycles

- ? increase steam T&P
- ? combined cycles →

Chemistry

- ? N_2O emissions
- ? NO_X – staged combustion
- ? post sulfur capture
- ? advanced sorbents
- ? Hg/air toxics/Cl
- ? low excess air firing
- ? condensables
- ? polishing systems – SO_2
- ? integrated APC – multipollutant
- ? improved SNCR – technology application
- ? effect of Cl – Hg & SO_2
- ? reaction rates – char, $CaSO_4$, *etc*.
- ? $CaSO_3$ $CaSO_4$ reactions/limitations

post sulfur capture sorbents

Conclusions

- Major efforts need to continue on the next generation options of supercritical designs, CFBs, and “advanced CFBs”.
- Environmental control development needs to be ongoing for SOx, Hg, NOx, and byproduct use.
- Innovative technology options for CO2 capture/sequestration from combustion systems is now emerging and should be pursued.
- Government, Industry, and University collaboration is advocated to develop and demonstrate new coal generation options

Coal combustion-based power is an important option for which innovations are possible and needed.

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